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Infant mortality in mid-19th century Amsterdam: Religion, social class, and space

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Abstract

This study uses a unique historical GIS dataset compiled from birth, death, and population register records for infants born in the city of Amsterdam in 1851 linked to micro-level spatial data on housing, infrastructure, and health care. Cox's proportional hazards models and the concept of egocentric neighbourhoods were used to analyse the effects of various sociodemographic characteristics, residential environment, water supply, and health-care variables on infant mortality and stillbirth. The analyses confirm the favourable position of the Jewish population with respect to infant mortality as found in other studies and show the unfavourable position of orthodox Protestant minorities. Infant mortality rate differences are much smaller between social classes than between religions. The exact role of housing and neighbourhood conditions vis-a-vis infant mortality is still unclear; however, we ascertained that effects of environmental conditions are more pronounced in later stages of infancy and less important in the early stages of infancy.

KEYWORDS

Amsterdam, egocentric neighbourhood, historical GIS, infant mortality, Netherlands, nineteenth century, religion, social class

1 | INTRODUCTION

As in many other mid-19th century cities and towns in the Netherlands, Amsterdam's local government showed indifference for a long time regarding its high levels of infant mortality. Although around 22% of children born in the mid-1850s did not survive past their first birthday, the Annual Report to the Municipal Council of 1853 stated that "the health situation of young children was in general rather sufficient, with the exception of the normal indispositions and the continuous or intermittent suffering of some children from certain diseases" (Gemeente Amsterdam, 1854, p. 57). However, a number of medical doctors gradually became more concerned than the local government about the high levels of infant and child mortality. They particularly referred to the very high mortality among the poorest and the enormous difference between the higher and lower classes of the urban population in terms of their health conditions and mortality risks. They proposed a health policy that could ensure the health of the whole population and not only of a small portion of its inhabitants (Houwaart, 1991). They argued that this necessitated a systematic analysis of the shortcomings in public health, an analysis that had to be based on topographical methods and on statistical analysis. This would bring to light the relationship between social and sanitary atrocities and high mortality. Once this analysis had been completed, health theory would be able to provide the necessary technical solutions to the hygiene problems of society. With that goal in mind, medical doctors started to collect statistical data on mortality and to analyse differences in mortality rates. In Amsterdam, these studies focused on the differences in mortality between the neighbourhoods constructed for official statistical purposes. The main question here was whether these differences had their origin in differences in prosperity (Bureau van Statistiek der Gemeente Amsterdam, 1936, 1952; Centrale Commissie voor de Statistiek, 1897; Israëls, 1850, 1862).[1]

Medical doctors were above all interested in the inequality in death risks among infants. For a "better and more confident future for humanity," a "healthy and powerful youth was a conditio sine qua non" and that made it necessary to be "aware of the vast dangers that threatened the infant in its earliest youth" (Israëls, 1862, 166). Large differences in infant mortality could indeed be observed between the neighbourhoods of Amsterdam. In some poor quarters, 35% of the live-born children in the mid-1850s died before their first birthday, whereas in a few well-to-do quarters infant mortality was less than 20%. A number of neighbourhoods, however, fell short of the expectation that the lower the prosperity of the neighbourhood, the higher the infant mortality rate (IMR): In the poor neighbourhoods directly southeast of the city centre, mainly inhabited by Jews, the mortality rate was clearly lower than could be expected on the basis of the income level of that neighbourhood (Van Poppel, 1983). Such a finding is a recurrent result in studies in the Netherlands (Van Poppel, Schellekens, & Liefbroer, 2002) and abroad (Connor, 2017; Derosas, 2003; Sawchuk, Tripp, & Melnychenko, 2013). Studies on Amsterdam explained this phenomenon by a variety of sometimes contradicting factors. Israëls (1862) referred to the fact that more Jewish mothers breastfed their children and also mentioned the specific location of the neighbourhood, as the Jewish quarters ostensibly suffered less from the effect of stagnant water and had no shortage of fresh air. A comparable argument was put forward by Egeling (1863) who suggested that although the Jewish population was "for the most part housed in a very miserable and cramped way," the neighbourhood nonetheless profited from being in a "rather favourable location, so that fresh air could freely run through." Coronel (1864) also mentioned the favourable effect of breastfeeding but stressed that this effect was restricted to the lower social classes. For Stephan (1904), the explanation lay in the better care that mothers provided and in the low prevalence of syphilis and alcoholism. Pinkhof (1907, 1908) argued that the main influence comprised not so much the physical characteristics of the neighbourhood but the lifestyle of the Jews.

Some authors have argued that at least part of the religious differences might be considered the result of a statistical artefact. Snel and Van Straten (2006) and Derosas (2004b) suggested that many analyses of the Jewish advantage in infant mortality are biased by a severe underestimation of neonatal mortality among Jews, as a large share of stillbirths were in fact neonatal deaths but were not included in the calculation of IMRs. There may have been a similar practice among Roman Catholics of registering stillbirths as live births that then were immediately recorded as having died ex utero. If these were true, the IMRs of Catholics would be too high and their stillbirth rates too low to reflect reality (Van Poppel, 2018).

In this study, we aim to unravel the complex relationship between infant mortality, socio-economic status, and religion in mid-19th century Amsterdam by analysing a unique historical cadastral map-based GIS dataset. The dataset is compiled from individual birth, death, and population register records related to infants born in the city of Amsterdam in 1851, which were then linked to micro-level spatial data on housing, infrastructure, and health care from the historical cadastral maps and other sources. We not only consider an ecological perspective by looking at geographically aggregated neighbourhood-level differences like the 19th century medical doctors already did but also take individual and household characteristics into account. Ecological studies of the effect of socio-economic status on mortality on the basis of spatial aggregated data have their advantages but do not directly answer the question whether differences in the socio-economic position of children lead to higher mortality. There is rarely a one-to-one relationship between prosperity or poverty of inhabitants of a neighbourhood and the prosperity or poverty level of that neighbourhood. Neighbourhoods are often rather heterogeneous, and ecological studies therefore underestimate the socio-economic variation in mortality because individuals with diverse characteristics are grouped together in one neighbourhood category (Sloggett & Joshi, 1994). Thus, the association between neighbourhood characteristics and mortality levels often disappears when the analysis takes into account the characteristics of the individuals living there.

This is not to say that individual-level data on socio-economic position and mortality are sufficient to answer the question of whether poverty is related to mortality risks. After all, it is possible that an association between neighbourhood characteristics and prosperity level of the inhabitants is in fact responsible for any observed relationship between mortality and prosperity. For example, in a mortality regime dominated by variation in the incidence of infectious diseases, it is the location of a socio-economic group in a spatially structured disease environment (presence of effective sewer system, or treated water) that mattered for mortality variation, not the advantages that go directly with the prosperity of individuals (Smith, 1991). It is by combining information about the situation of the neighbourhood with information on characteristics of the individuals living there that allows one to unravel the effects of socio-economic position and neighbourhood (Williams, 1992).

The same applies to the role that religion plays in the religion-neighbourhood-mortality equation. To find out whether religion played a greater role than that of the neighbourhood where the religious groups lived, it is necessary to obtain individual-level information about the religion of the population at risk and of the deceased.

This study not only focuses on the mortality of infants but also has implications for mortality in general. Infant mortality in the 19th century accounted for a very high proportion of the total number of deaths and determined to a large degree the level of the expectation of life at birth and the changes therein.

2 | AMSTERDAM MID-19TH CENTURY

Around 1850, Amsterdam had approximately 225,000 inhabitants—slightly more than at the beginning of the 19th century. The city was one of the top 20 largest cities in Europe and among the top 40 in the world at the time (Chandler & Fox, 1974, p. 361). Only in the last

[1]These kinds of ecological studies remained in fashion until far into the 20th century (Van de Mheen, Reijneveld, & Mackenbach, 1996; Van der Maas, Habbema, & Van den Bos, 1987).

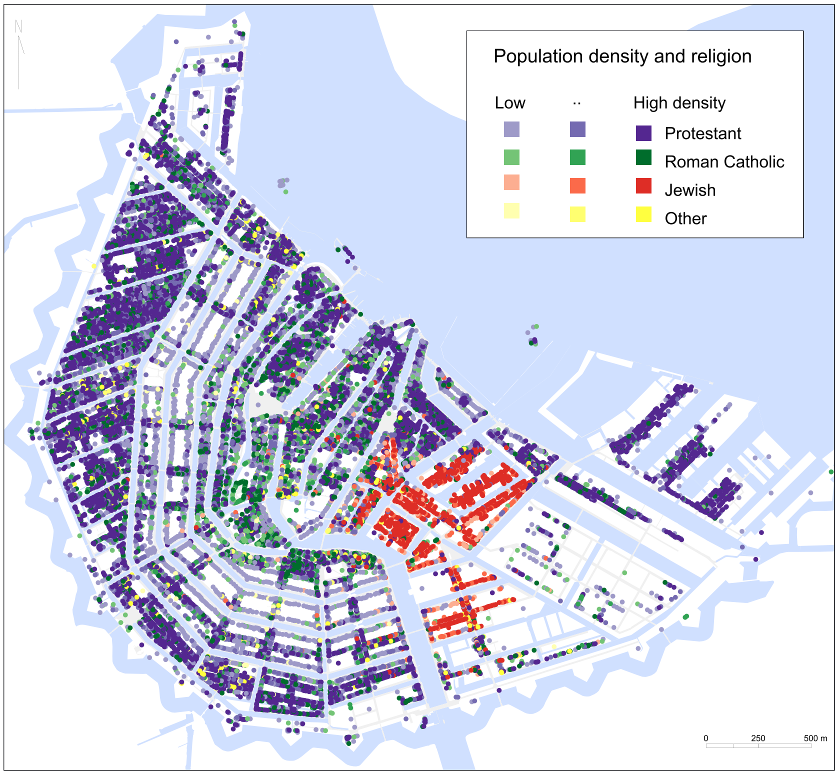

FIGURE 1 Population density and main religious denomination by premises, Amsterdam, 1851.
Source: own calculations based on Amsterdam Population Register 1851–1853 and HISGIS Amsterdam

quarter of the 19th century did the population of Amsterdam start to increase rapidly, so that by the end of the 19th century, the population had more than doubled to 510,000 inhabitants.

In the middle of the 19th century, the more recently developed areas at the border of the city were very densely populated, and that applied also to the harbour area and the area southeast of the city centre known as the Jewish neighbourhood (see Figure 1). About 65% of the population of Amsterdam belonged to one of the many Protestant denominations; 22% was Roman Catholic, and 11% was Jewish. As far as the social class composition was concerned, the city was predominantly working class. Only 2% of the population was classified as elite, 20% middle class, 22% skilled labourers, 37% semi-skilled labourers, and 19% unskilled labourers.[2] The Jewish population, from all social classes, lived in very concentrated clusters near their synagogues in the eastern part of the city. The lower class population was concentrated in the most densely populated areas on the outskirts of the city, whereas the elites mainly lived in the relatively sparsely populated area in the canal district just outside the old city to the south and east. Although the wealthiest and poorest people (except for the Jewish population) did not share the same living space, location and related rental prices resulted in differentiation at street level and even at the level of houses and floors within the same street (Lesger & Leeuwen, 2012).

IMRs in Amsterdam were high during most of the 19th century: around 200 per 1,000 live births for girls and around 235 per 1,000 for boys. From 1885, IMRs started to decline (see Figure 2); the stillbirth rate was again higher for boys than for girls: around 60 per 1,000 births for boys and 50 per 1,000 for girls, but started decreasing

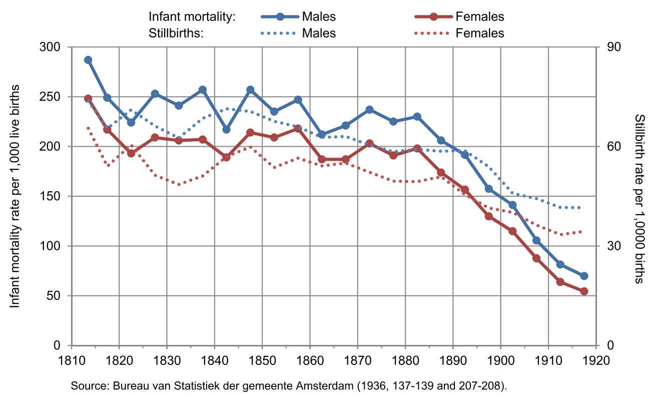

FIGURE 2 Infant mortality and stillbirth rates, Amsterdam, 1812–1919

halfway through the 19th century (Figure 2). IMRs were particularly high in the densely populated poorer areas in the west, east, and south of the city. IMRs, however, were relatively low in the thinly populated richer parts of the city and in the densely populated (poor) Jewish neighbourhood (Figure 3).

Several studies stressed the importance of the impact of water and sanitation on (infant) mortality rates in the 19th century, such as Van Poppel and Van der Heijden (1997) on clean water supply, Jaadla and Puur (2016) on water supply and sanitation, and Kesztenbaum and Rosenthal (2017) on sanitation and sewage. The high IMRs in Amsterdam are thought to be related to the fact that much of the surface and ground water in the western provinces of the Netherlands was heavily contaminated. Canals were often used for the disposal of waste, and the water from the canals was also used for household purposes by the poor (Van Poppel et al., 2002). Although several—not always very realistic and often far too expensive—plans had been proposed to

[2]Own calculations using application of the Social Power scheme (Van de Putte & Miles, 2005) to the Amsterdam population register data 1851.

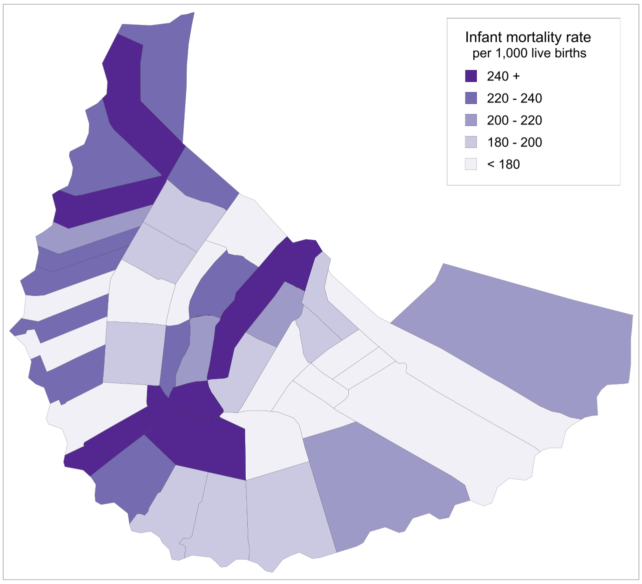

FIGURE 3 Infant mortality rates by neighbourhood, Amsterdam, 1854–1859.
Source: Bureau van Statistiek der Gemeente Amsterdam 1854–1859

improve the water quality, only by the end of the 18th century did the city government finally approve a plan to build cisterns for the storage of fresh water (Groen, 1978). The cisterns were not only primarily meant for the brewers but also served the general population who could afford the water. Until the 1850s, however, water was also supplied from neighbouring regions, transported to Amsterdam and distributed and sold in barrels from small vessels within the city. But the poor remained dependent on the bad quality water from the canals and rain barrels. Only in 1853 did the city finally implement a water supply system, and it was not until 1906 that a city-wide sewer system was built.

Medical doctors in the 19th century (such as Israëls, 1850, 1862; Nieuwenhuys, 1816) already pointed to the unhealthy circumstances due to bad quality water and sanitation, particularly in the poor neighbourhoods of the city, and the need for public health policy. But to what extent was the health situation affected by the availability and quality of medical care itself? Woods, Løkke, and Van Poppel (2006) point to the effect of either the absence of trained midwives and medical doctors or the introduction of and improvements in the quality of obstetric care on levels of perinatal and infant mortality in 19th century Denmark, England and Wales, the Netherlands, Norway, and Sweden. Differences in obstetric care might also have existed at the local level. Israëls (1862), for instance, noted a very high infant mortality in several Amsterdam neighbourhoods during the 1850s due to convulsions, which made him conclude either that medical practitioners did not take their work seriously enough or that they were not consulted often enough in the case of children and that therefore children died without any proper treatment due to lack of medical knowledge. Use of medical care could also have varied between religious groups. Jewish communities in particular developed a variety of welfare institutions and services, providing assistance and help with, among other things, medical care (Derosas, 2003), and Jews were thought to have made better use of medical care when available (Van Poppel et al., 2002).

In the 19th century in Amsterdam (as in the rest of the Netherlands), especially, midwives played an important role in health care with respect to delivery and birth. In the 19th century, medical practitioners were organised into various groups (Van Lieburg & Marland, 1989) that included the nonacademically trained midwives ("vroedvrouwen") and man-midwives ("vroedmeesters"), as well as the academically trained doctors of obstetrics (who were also qualified as medical doctors). Midwives had to be educated for at least 1 year and then to be trained through an apprenticeship to a licensed midwife. Midwives supervised most normal deliveries and were instructed to call in obstetric doctors or man-midwives in difficult or dangerous cases. Although obstetric doctors and man-midwives were trained differently, the obstetric doctors had to follow the instructions laid down for the man-midwives (Van Lieburg & Marland, 1989). A few "city" midwives ("stadsvroedvrouwen") were specially appointed and paid by the city to help the poor. According to the population register of 1851, there were about 64 midwives (of which two "city" midwives) and 46 man-midwives in Amsterdam; that is on average 4.9 (man) midwives per 10,000 inhabitants and 78 births per (man) midwife per year. The total number of medical doctors was around 140, but the number of obstetric doctors among them remains unknown.

3 | INDIVIDUAL-LEVEL SOCIODEMOGRAPHIC AND MICRO-LEVEL SPATIAL DATA

Individual-level data about the relation between the socio-economic position and mortality have become available for Amsterdam only since the end of the 1930s (Bureau van Statistiek der Gemeente Amsterdam, 1953). For some other Dutch cities, individual-level data for the last quarter of the 19th century were published at the time, but these data are not very detailed and do not lend themselves to more refined analysis (for an overview, see Van Poppel, 1983). More recently, rather detailed individual-level data have become available from the random Historical Sample of the Netherlands, but these data are not very well suited for detailed analyses of the effect of place of residence on mortality (Van Poppel, Jonker, & Mandemakers, 2005). Digitalized data from the Amsterdam population register 1851–1853,[3] however, offer a unique possibility to study the relationship between mortality and the socio-economic position of the child, the religion of the parents, and other familial characteristics, some highly relevant characteristics of the houses and the neighbourhood in which these families lived.

Findings of Hedefalk, Pantazatou, Quaranta, and Harrie (2017), Hedefalk, Quaranta, and Bengtsson (2017), and Olson (2017), for instance, show that the choice of geographical level is important for demographic analyses using historical individual-level data. Hedefalk, Pantazatou, et al. (2017) and Hedefalk, Quaranta, et al. (2017) combine micro-level geographical factors, such as soil conditions, with individual-level historical demographic data in a case study of rural parishes in Sweden. Studies analysing micro-level geographic factors for urban environments have also become more common; see, for

[3]Amsterdam City Archive, Archive of the Population Registers (collection 5000), Population Registers 1851–1853 (inventory nos. 258–994; Part 1).

example, Olson (2017) and Thornton and Olson (2011) for Montreal, and Ekamper (2012) for the Dutch town of Leeuwarden. Some recent studies explicitly focusing on 19th and early 20th century infant and child mortality at the geographical micro-level have been done for Dublin 1911 (Connor, 2017), Gibraltar 1874–1881 (Sawchuk et al., 2013), Newark 1880 (Xu, Logan, & Short, 2014), and Tartu 1897–1900 (Jaadla & Puur, 2016).

This study relates to mortality in the first year of life among children born during the year 1851 in Amsterdam. We are able to determine the child's socio-economic position (on the basis of the occupation of the father), the religion, the age of the mother at the time of birth of the child, and the number of other persons present at the same address. By adding information on stillbirths from the vital registration system, we also can shed light on the question whether religious differences in mortality were in fact caused by different registration practices that had their basis in religious customs and beliefs. This study will also use spatial information from the Dutch cadastral maps and corresponding cadastral registers, the most detailed geographical source available for the mid-19th century. The large-scale cadastral maps and cadastral registers provide information at the spatial micro-level of parcels and buildings, such as location, size, and value of the property. Although individual-level information on sanitation and health-care use is not available, combining the cadastral map and population register data allows the creation of rough indicators. The cadastral maps can be used to derive information at the spatial micro-level on the surrounding environment, for example, proximity to (fresh) water and width of streets. Linking population register data on health-care professionals to the cadastral map data allows us to determine the geographical proximity of persons to for instance medical practitioners.

By combining the precise address location of the residence of each individual in 1851 from the population register with the digitised version of the cadastral map of Amsterdam from the HISGIS Amsterdam project,[4] we are therefore able to study

- whether there were socio-economic mortality differences in infant mortality;
- whether housing/neighbourhood conditions reinforced or weakened these mortality differences;
- whether or not some specific religious groups were able to escape from this situation via specific health practices and lifestyles; and
- whether the proximity of health-care weakened mortality differences.

4 | DATA SOURCES

Population registers, enforced in the Netherlands by the Royal Decree of December 22, 1849, combine census listings with vital registration in an already linked format for the entire population of a municipality with the household as the registration unit (Alter, 1988, pp. 32–58; Meijer, 1983). For each household member name, date and place of birth, marital status, occupation, religion, and if applicable, date of death, date of moving in and date of moving out were recorded. New household members, including newborns, were added to the list of individuals already recorded, and those moving out due to death or migration were cancelled with reference to place and date of migration or date of death. The first Amsterdam population register covers all neighbourhood section population registers over the years 1851–1853, with the exception of one small register, neighbourhood F section 1, which was lost. The population register is ordered by address instead of by person, which means that persons can appear more than once in the register. The names of persons who were registered at a certain address and moved were crossed out and entered again at the new address. Dates of departure and arrival were added at the respective addresses in the register. Although family relationships between household members were not registered, birth dates, marital states, and family names can be helpful in deriving these relationships. The information in the registers was given orally. Sometimes, exact birth dates are missing or not consistent with other dates. First and last names sometimes differ between multiple entrances of the same person or compared with the civil registration.

We selected from the register the cohort of all children born in the year 1851 and tracked their survival up to their first birthday. We compared these birth data with the birth register of the civil registration to correct for missing or unidentified births and duplicate registries in the population register. We also added stillbirths from the death register of the civil registration including information on the parents from the death certificates. The birth and death certificates provide less information on the parents than the population register, most importantly, the age of the mother and the religion are not stated. But by using the available data on parents' family names, age of the father, and residential address, missing data could be traced in the population register or marriage certificates.

Our total initial dataset includes 8,871 births, of which 7,645 births were listed in the population register, 703 additional births were listed in the civil registration, and 523 were stillbirths. We left out all births of children not born at a permanent address (mainly a few foundlings and children born on board of ships temporarily docked in Amsterdam) and all births in the more rural area outside the ramparts ("stadswal").[5] Most of the latter addresses could not be linked to the cadastral maps because some of the maps of this area have been lost from the archives. Our remaining total dataset includes 8,636 births, of which 512 were stillbirths (5.9%) and 1,682 were infants (19.5%) that died within the first year of life.

From the population register, we can determine for all newborns the date of birth, date of death (if they died in the period 1851–1853), sex of the child, the age of the father and the mother at the time of birth of the child, religion, occupation of the father, home address of the parents, and the number of persons living at the same address. For the additional births from the civil register, we checked in the death certificates of 1851 and 1852 whether the infants died within their first year of life. We added sex of the child, age and

[4]Historical Geographical Information System (HISGIS) Amsterdam (Feikens, 2013).

[5]We had to leave out 49 children not born at a permanent address in Amsterdam and which were also not listed in the population register (43 born on ships temporarily docked in Amsterdam, five foundlings, and one child born in a waffle stall), and 186 children born outside the ramparts.

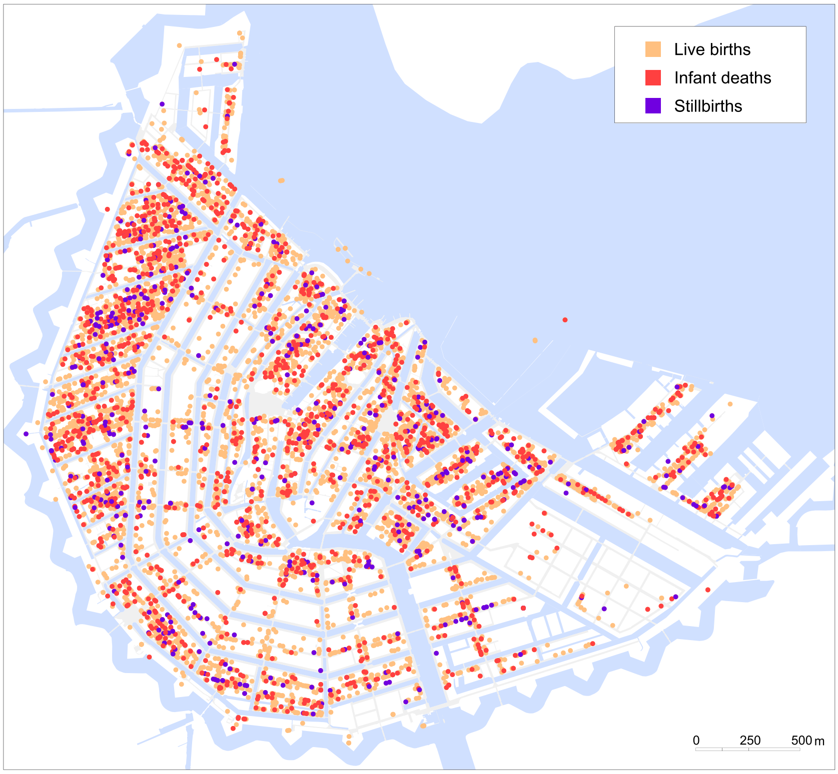

FIGURE 4 Live births, stillbirths, and infant deaths by premises, Amsterdam, children born in 1851.
Source: Amsterdam population register 1851–1853, Amsterdam civil registration 1851–1852, and HISGIS Amsterdam

occupation of the father, and home address of the parents from the birth certificates and used this information to trace the parents in the population register to add data on the religion and the age of the mother. If not found in the population register, we used data from the marriage certificates. Figure 4 presents the spatial distribution of the live births, stillbirths, and infant deaths.

From the cadastral maps and corresponding cadastral registers, we can add the tax value, the exact geographical location (longitude and latitude coordinates), and the area of the building. From this source, we can also compute the widths of the streets, proximity to surface water (canals), and determine whether the house is located directly in front of a canal or in a backstreet alley ("slop"). We collected additional data from historical maps of Amsterdam on the location of public cisterns[6] for availability of fresh water and on the watercourses through the city to get at least a rough indication of the water quality of the canals.[7] We were not able to track historical data on (potentially unhealthy) wet soil conditions due to differences in micro-level altitudes (height above sea level) and therefore used contemporary data.[8] Because many of the historical buildings in the study area still exist, we assume that the current situation still reflects the historical situation with lowest areas in the west and higher areas in the east and north. The lack of institutional public health facilities in the Netherlands meant that most women, rich or poor, had their babies at home, resulting in a very low incidence of hospital births (Van Lieburg & Marland, 1989). Dutch women regarded the hospital as the last resort, not least because of the poor conditions prevailing in these institutions (Van Lieburg & Marland, 1989). If anyone assisted with the deliveries at all, it was usually the midwives; the man-midwives or doctors intervened in complicated situations. Linking the population register data on midwives, man-midwives, and medical doctors to the cadastral map data allows us to determine the geographical proximity to these medical practitioners. Figure 5 maps a selection of the additional cadastral, environmental, and health-care data.

5 | METHODS

To analyse the effect of various sociodemographic characteristics, residential environment, water supply, and health care on infant mortality, we applied Cox's proportional hazards models (Cox, 1972) to our study population of live births.[9] The dependent variable is the hazard of infant death. We calculated exposures measured in days from the date of birth up to the date of death or, for those surviving their first year of life, up to their first birthday. Research into infant mortality has shown that environmental and water supply factors gain importance after the first months of life (Jaadla & Puur, 2016; Van Poppel &

[6]Locations of public cisterns taken from the second edition of the map of Amsterdam scale 1:8,250 by C. van Baarsel & Son (1826) with watercourses annotated in red (Amsterdam City Archives, collection 10095, Atlas Kok, nr. 223).

[7]Water quality derived from the first edition of a map of Amsterdam scale 1:10,000 by A.J. van der Stok (1873) marking a new plan for waterworks solving drainage problems (Amsterdam City Archives, collection 10035). Although the map dates much later than 1851, its ground layer shows the drainage situation that already existed well before 1851. We are therefore confident that it reflects the water quality around that time.

[8]Altitude data 2015 from Actueel Hoogtebestand Nederland (AHN).

[9]Running Gompertz hazards models did not produce different results from the reported Cox models (not shown).

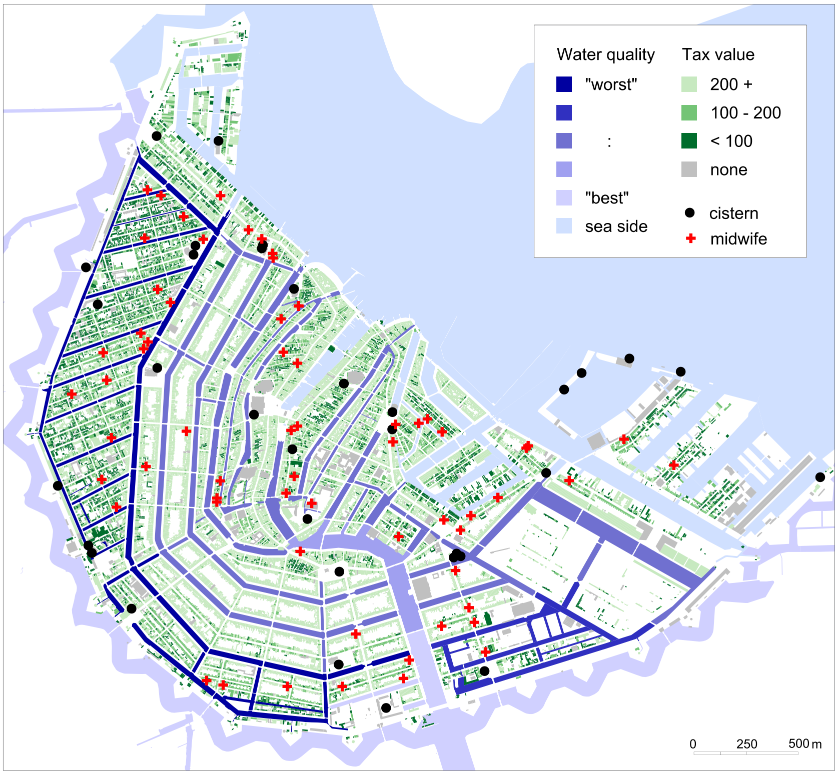

FIGURE 5 Tax values per dwelling, canal water quality, locations of cisterns, and residential locations of midwives in Amsterdam around 1850.
Source: Amsterdam population register 1851–1853, Amsterdam maps by Van Baarsel and Son (1826)[6] and Van der Stok (1873)[7], HISGIS Amsterdam

Van der Heijden, 1997), particularly from the time that weaning starts (Knodel & Kintner, 1977; Reid, 2002, 2017). In line with Jaadla and Puur (2016), we therefore also used a multiepisode model for two stages of infancy: "early" infancy (Months 0–5) and "later" infancy (Months 6–11).

Although stillbirths might be less associated with social class and more an indication of a woman's physical health, it is generally influenced by poverty (Edvinsson, Brändström, Rogers, & Broström, 2005). However, religious differences with respect to stillbirths might in fact reflect different registration practices rather than religious customs and beliefs. Jewish stillbirth rates, for instance, might be biased by overestimation because Jews were much more likely to register spontaneously aborted foetuses as stillbirths as soon as they could be recognised as a human being (Snel & Van Straten, 2006). We therefore used logistic regression models to compare the binary outcomes of the risk of stillbirths and infant mortality using the same set of independent variables.

The following variables were included in our Cox's and logistic regression models: age of the child (in days), sex of the child, age of the mother at birth, age difference with the father, single motherhood, single or multiple birth(s), religion, social class, number of people living at the same address, population density at the housing level, season of birth, tax value of the property, living in a backstreet alley, street width, altitude, living directly in front of a canal, distance to the nearest surface water, water quality, distance to the nearest public cistern, distance to the nearest midwife, distance to the nearest man-midwife, and distance to the nearest medical doctor. See Table 1 for descriptive statistics of the study population with respect to all variables.

Age of the mother is classified in five age groups from age under 25 to age 40+ in order to account for higher risks of young and old mothers (Knodel & Hermalin, 1984; Tymicki, 2009). Because the ages of mother and father are highly correlated, we have included the difference between the age of the father and the age of the mother to account for possible effects of younger or older fathers (Barclay & Myrskylä, 2018). Religion, originally classified in 15 categories, has been aggregated into 10 categories: Dutch Reformed, Evangelical Lutheran, Restored Evangelical Lutheran, Mennonites, Walloon Reformed, other Protestants (including Christian Dissenters, English Reformed, Episcopalians, Presbyterians, and Scottish Protestants), Roman Catholics (including Roman Catholics and Old Catholics), Dutch (Ashkenazic) Jewish, Portuguese (Sephardic) Jewish, and unknown.[10] Social class is classified in five categories using the application of the Social Power scheme to the occupation of the father (or mother if father is unknown): elite, middle class, skilled workers, semi-skilled workers, and unskilled workers (Van de Putte & Miles, 2005). Because the population register does not clearly differentiate separate households within the same address, the number of persons living at the same address is used. Population density is calculated as the number of persons living at the same address per 10 m^2 of the area of the residential building according to the cadastral register. Season of birth is classified as spring (March to May), summer (June to August), autumn (September to November), and winter (January, February, and December).

Using our historical GIS, we are able to derive the geographical coordinates and attributes of the spatial variables. This includes the annual tax value and area of the residential building taken from the cadastral register as well as the physical immediate neighbourhood

[10]In line with the recordings in the population register, we will use the terms Dutch Jewish and Portuguese Jewish instead of Ashkenazic Jewish and Sephardic Jewish.

TABLE 1 Infant mortality rates (IMR), stillbirth rates, and percentage distributions of infants alive at age 1, infant deaths, and still births by explanatory and control variables, Amsterdam, children born in 1851

Variables	IMR ‰ live births	Stillbirth rate ‰ births	Infants alive %	Infant deaths	Stillbirths	All
Socio demographics						
Sex						
Male	222	66	49.9	54.5	56.8	51.2
Female	191	53	50.1	45.2	43.2	48.7
Age of mother at birth (in years)						
<25	235	54	11.2	13.1	10.5	11.5
25–29	193	49	22.6	20.7	18.4	22.0
30–34	191	61	27.3	24.6	27.5	26.8
35–39	198	60	18.2	17.2	18.2	18.0
40+	235	68	11.8	13.9	14.3	12.4
Unknown	232	71	8.9	10.3	11.1	9.3
Age difference with father						
2 or more years younger	196	64	21.1	19.8	22.7	21.0
Around same age	193	46	26.1	23.9	19.5	25.3
2 to 9 years older	193	54	39.5	36.2	35.4	38.6
10 or more years older	187	48	10.1	8.9	7.8	9.7
Single mother						
No	193	54	97.2	89.3	85.9	95.0
Yes	501	163	2.8	10.7	13.7	5.0
Multiple birth						
No	200	58	98.2	94.0	95.5	97.3
Yes	472	97	1.8	6.0	4.5	2.7
Religion						
Dutch Reformed	214	54	47.9	49.9	44.1	48.1
Evangelical Lutheran	229	60	11.4	13.0	11.9	11.7
Restored Evangelical Lutheran	274	63	2.7	3.9	3.1	2.9
Mennonites	196	58	1.2	1.1	1.2	1.2
Walloon Reformed	160	38	0.7	0.5	0.4	0.6
Remonstrants	194	88	0.4	0.4	0.6	0.4
Other Protestants	262	45	0.5	0.7	0.4	0.5
Roman Catholics	210	57	21.4	21.8	20.7	21.4
Dutch-Jewish	135	76	12.0	7.1	14.3	11.2
Portuguese-Jewish	78	37	1.5	0.5	0.8	1.2
Social class						
Unskilled workers	197	51	19.8	18.6	16.8	19.4
Semi-skilled workers	228	67	17.3	19.6	20.3	17.9
Skilled workers	208	50	32.9	33.2	27.7	32.7
Middle class	182	62	23.7	20.2	24.2	23.1
Elite	156	45	2.5	1.8	1.8	2.3
No occupation/unknown	314	118	3.8	6.6	9.2	4.6
Number of persons at same address						
<6	206	74	9.9	9.8	12.5	10.0
6–9	213	53	17.8	18.5	15.8	17.8
10–14	216	57	24.6	25.9	23.6	24.8
15–24	206	58	30.5	30.4	29.9	30.4
25+	184	61	14.7	12.7	14.6	14.3

(Continues)

TABLE 1 (Continued)

Variables		IMR ‰ live births	Stillbirth rate ‰ births	Infants alive %	Infant deaths	Stillbirths	All
Population density (persons per 10 m^2)							
<1.25		191	62	14.7	13.3	15.2	14.5
1.25–2.50		206	58	24.6	24.4	24.2	24.6
2.50–5.00		219	58	37.6	40.3	37.1	38.1
5.00 +		197	59	20.4	19.1	19.9	20.1
Season of birth							
Winter		224	59	25.5	28.1	26.0	26.0
Spring		195	64	27.5	25.5	29.3	27.2
Summer		206	58	24.2	24.0	23.4	24.1
Autumn		203	56	22.9	22.4	21.3	22.7
Residential environment							
Tax value							
<100		217	59	27.8	29.5	28.1	28.2
100–200		211	61	40.7	41.8	42.0	41.0
200+		191	58	31.0	27.9	29.9	30.3
Backstreet alley							
No		203	59	82.6	80.6	81.4	82.1
Yes		226	62	17.4	19.4	18.6	17.9
Street width (m)							
<4		202	69	12.9	12.5	15.0	12.9
4–8		212	59	44.1	45.4	44.5	44.4
8+		196	59	37.7	35.3	36.7	37.2
Altitude (m)							
<0.5		215	61	14.1	14.7	14.6	14.2
0.5–1.0		205	58	34.4	34.0	33.8	34.3
1.0–1.5		217	62	24.3	25.9	26.0	24.7
1.5 +		195	57	27.2	25.3	25.6	26.7
Water supply							
House in front of canal/water							
No		212	62	72.5	74.6	76.2	73.1
Yes		194	53	27.4	25.3	23.8	26.8
Distance to nearest surface water (m)							
<15		201	54	29.9	28.8	26.8	29.5
15–30		200	61	20.8	19.9	21.1	20.6
30–45		213	60	22.0	22.8	22.5	22.2
45–60		211	69	14.8	15.2	17.4	15.0
60+		218	58	12.4	13.3	12.3	12.6
Water quality canals							
Sea side	IJ (North)	196	57	25.1	23.4	23.8	24.7
"best"	Nieuwevaart	191	81	0.9	0.8	1.2	0.9
	Amstel	190	56	1.1	1.0	1.0	1.0
:	Centre	198	58	32.6	30.8	31.4	32.2
	East	266	65	1.6	2.3	2.0	1.8
"worst"	West	220	61	38.7	41.7	40.6	39.4
Distance to nearest public cistern (m)							
<100		206	47	13.0	13.0	10.2	12.8
100–200		228	63	31.4	35.5	34.6	32.4
200–300		190	62	33.3	29.9	34.2	32.7
300–400		208	54	14.7	14.9	13.5	14.7
400+		189	62	7.5	6.7	7.6	7.3

(Continues)

TABLE 1 (Continued)

Variables	IMR ‰ live births	Stillbirth rate ‰ births	Infants alive %	Infant deaths	Stillbirths	All
Health care						
Distance to nearest midwife (m)						
<75	197	59	30.9	29.0	30.3	30.5
75–150	204	63	35.7	35.0	37.9	35.7
150–300	212	56	26.9	27.7	25.4	27.0
300+	251	57	6.4	8.2	6.4	6.8
Distance to nearest man-midwife (m)						
<100	202	59	20.4	19.9	20.1	20.3
100–200	200	57	29.6	28.4	27.9	29.3
200–400	210	65	32.2	32.8	35.5	32.5
400–800	222	58	11.6	12.7	11.5	11.8
800+	209	49	6.0	6.1	4.9	5.9
Distance to nearest medical doctor (m)						
<75	204	62	46.0	45.1	47.7	45.9
75–150	199	55	29.5	28.1	27.1	29.1
150–300	220	60	19.0	20.6	19.7	19.4
300+	227	58	5.4	6.1	5.5	5.6
All	207	59	100.0	100.0	100.0	100.0
Number of observations	8,124	8,636	6,442 (74.6%)	1,682 (19.5%)	512 (5.9%)	8,636 (100%)

Source: Amsterdam population register 1851–1853; Amsterdam civil registration 1851–1852.

characteristics such as street width in front of the house, whether the house is located at a backstreet alley, whether it is in front of a canal, and water quality of the canal. We calculated straight line distances from all the residential locations where children were born to the nearest surface water and to the nearest of the 33 public cisterns throughout the city. Because by far most women had their babies not in hospitals, but at home (Van Lieburg & Marland, 1989), we similarly calculated distances to the residential location of the nearest medical practitioners involved in health care with respect to delivery and birth: the midwives, the man-midwives, and the doctors.

To address effects of neighbourhood-level differences on mortality, an important methodological issue is the classification of neighbourhoods. Studies of neighbourhood effects on health have often relied heavily on administratively defined units (such as census districts) to measure neighbourhood characteristics (Xu et al., 2014). However, administratively defined areal boundaries do not necessarily coincide with those of everyday life experience and may cause statistical bias by the modifiable areal unit problem, which may in turn hinder us from detecting underlying neighbourhood effects (Xu et al., 2014). To address these issues, Östh, Clark, and Malmberg (2015) and Clark, Anderson, Östh, and Malmberg (2015) propose the use of the concept of egocentric neighbourhoods based on population size, enabling the construction of neighbourhood measures that are computed in exactly the same way across different urban areas. Neighbourhood measures can then be calculated for each individual separately based on aggregation of a predefined number (*k*) of that individual's nearest neighbours. We will use egocentric neighbourhood measures for the spatial isolation index as used in Östh et al. (2015) and the diversity index (Theil, 1972) used in Xu, Logan, and Short (2014) and Connor (2017). The isolation index reflects the probability (ranging from 0 to 1) of a person of a specific population subgroup (such as a religious minority) to meet a member of that same subgroup within the person's neighbourhood. The diversity index is an entropy-based measure that reflects the residential (un)evenness of population subgroups in a neighbourhood, ranging from 0 (indicating the least diversity with a single group dominating the neighbourhood) to 1 (indicating the greatest diversity).

6 | RESULTS

For the cohort of children born in Amsterdam in 1851, the overall IMR was 207 per 1,000 live births. This is about 15% higher than the national average for the years 1851–1852. The stillbirth rate was 59 per 1,000, about 25% higher than the national average. These above-average mortality rates in Amsterdam fit with the widespread mortality disadvantage to living in urban places ("urban penalty") in the 19th century (Haines, 2001; Kearns, 1988; Reher, 2001; Schofield, Reher, & Bideau, 1991; Van de Walle, 1986).

To analyse the risk of infant mortality with all explanatory and control variables from Table 1 simultaneously, we used Cox proportional hazards regression models. The results are presented in Table 2. The second data column shows the infant mortality risk of all live birth outcomes of the full multiple regression model including all explanatory and control variables simultaneously. As a reference, the first data column shows the outcomes of Cox proportional hazards regression models that we ran for infant mortality risk, combined with

TABLE 2 Cox proportional hazards model hazard ratios (HR) for infant mortality by explanatory and control variables, Amsterdam, children born in 1851

Variables	Nonadjusted HR	Adjusted HR	Adjusted: Periods of infancy, 0–5 Months HR	Adjusted: Periods of infancy, 6–11 Months HR
Socio demographics				
Sex				
Male	1.18***	1.20***	1.16**	1.32***
Female	1.00	1.00	1.00	1.00
Age of mother at birth (in years)				
<25	1.27***	1.14	1.20*	0.99
25–29	1.02	0.97	1.02	0.83
30–34	1.00	1.00	1.00	1.00
35–39	1.04	1.03	1.02	1.05
40+	1.27***	1.33***	1.29**	1.41**
Unknown	1.25**	1.13	1.16	1.06
Age difference with father				
2 or more years younger	1.02	0.97	1.01	0.89
Around same age	1.00	1.02	1.02	1.01
2 to 9 years older	1.00	1.00	1.00	1.00
10 or more years older	0.96	0.97	0.93	1.05
Single mother				
No	1.00	1.00	1.00	1.00
Yes	3.25***	2.92***	2.88***	2.78*
Multiple birth				
No	1.00	1.00	1.00	1.00
Yes	3.14***	3.18***	3.57***	2.00**
Religion				
Dutch Reformed	1.00	1.00	1.00	1.00
Evangelical Lutheran	1.09	1.11	1.23**	0.83
Restored Evangelical Lutheran	1.32**	1.38**	1.21	1.84**
Mennonites	0.89	1.02	0.84	1.36
Walloon Reformed	0.72	0.85	0.77	1.01
Remonstrants	0.90	1.09	1.09	1.09
Other Protestants	1.20	1.38	1.06	2.17*
Roman Catholics	0.98	1.01	0.98	1.04
Dutch-Jewish	0.61***	0.70***	0.74**	0.60**
Portuguese-Jewish	0.34***	0.40**	0.37**	0.43
Social class				
Unskilled workers	1.00	1.00	1.00	1.00
Semi-skilled workers	1.18**	1.07	1.03	1.18
Skilled workers	1.06	1.09	1.08	1.13
Middle class	0.91	1.02	0.92	1.30*
Elite	0.77	0.88	0.89	0.89
No occupation/unknown	1.73***	1.01	0.97	1.15
Number of persons at same address				
<6	1.00	1.00	1.00	1.00
6–9	1.05	0.98	1.08	0.77
10–14	1.06	0.92	1.07	0.62**
15–24	1.02	0.87	1.03	0.58**
25+	0.89	0.80	0.88	0.62*

(Continues)

TABLE 2 (Continued)

Variables		Nonadjusted HR	Adjusted HR	Periods of infancy: 0–5 Months HR	Periods of infancy: 6–11 Months HR
Population density (persons per 10 m^2)					
<1.25		0.85**	0.81**	0.87	0.67**
1.25–2.50		0.93	0.91	0.87	1.00
2.50–5.00		1.00	1.00	1.00	1.00
5.00+		0.88*	0.96	0.95	0.98
Season of birth					
Winter		1.10	1.06	1.04	1.11
Spring		0.95	0.96	1.05	0.74**
Summer		1.00	1.00	1.00	1.00
Autumn		0.99	0.98	0.94	1.05
Residential environment					
Tax value					
<100		1.03	0.95	1.04	0.72**
100–200		1.00	1.00	1.00	1.00
200+		0.89*	0.98	0.94	1.06
Backstreet alley					
No		1.00	1.00	1.00	1.00
Yes		1.14**	1.29**	1.26*	1.36
Street width (m)					
<4		0.96	0.73**	0.81	0.56**
4–8		1.00	1.00	1.00	1.00
8+		0.92	0.97	1.03	0.85
Altitude (m)					
<0.5		1.05	1.02	1.03	0.98
0.5–1.0		1.00	1.00	1.00	1.00
1.0–1.5		1.07	1.05	1.11	0.91
1.5+		0.95	1.05	1.15	0.84
Water supply					
House in front of canal/water					
No		1.00	1.00	1.00	1.00
Yes		0.91*	0.89	0.94	0.80
Distance to nearest surface water (m)					
<15		1.00	1.00	1.00	1.00
15–30		0.99	0.89	0.85	1.00
30–45		1.07	0.94	0.92	0.99
45–60		1.06	0.89	0.89	0.90
60+		1.10	0.94	0.91	1.04
Water quality canals					
Sea side	IJ (North)	1.00	1.00	1.00	1.00
“best”	Nieuwevaart	0.96	0.81	0.81	1.03
	Amstel	0.97	0.91	0.90	0.93
:	Centre	1.01	1.03	1.05	0.99
	East	1.40**	1.39*	1.20	1.92**
“worst”	West	1.14**	1.05	1.07	1.02

(Continues)

TABLE 2 (Continued)

Variables	Nonadjusted HR	Adjusted HR	Periods of infancy 0–5 Months HR	6–11 Months HR
Distance to nearest public cistern (m)				
<100	1.00	1.00	1.00	1.00
100–200	1.12	1.13	1.05	1.37***
200–300	0.91	0.99	0.94	1.13
300–400	1.02	1.07	1.07	1.09
400+	0.90	0.92	0.82	1.25
Health care				
Distance to nearest midwife (m)				
<75	1.00	1.00	1.00	1.00
75–150	1.05	1.03	1.11	0.86
150–300	1.09	1.08	1.09	1.06
300+	1.32***	1.20*	1.19	1.18
Model				
Number of observations	8,124	8,124	8,124	6,926
Number of infant deaths	1,682	1,682	1,201	484
Log-likelihood		−14,761.9	−10.557.0	−4191.5
Likelihood ratio χ^2		387.4	324.5	142.7
Degrees of freedom		67	68	68
p value		0.00	0.00	0.00

Note. Nonadjusted models were run for each variable separately.

**p* < 0.1 significance. ***p* < 0.05 significance. ****p* < 0.01 significance.

Source: Amsterdam population register 1851–1853; Amsterdam civil registration 1851–1852.

each individual explanatory or control variable separately without all other explanatory or control variables.

6.1 | Religion

The Amsterdam population register provides quite detailed information on religious denominations in Amsterdam; 15 denominations in total, most of them dissented Protestant denominations (see Table A1), condensed into 10 categories in the Cox models (see Table 2). The Jewish denominations stand out in a positive way, with hazard ratios 31% lower for Dutch Jewish and 61% lower for Portuguese Jewish compared with the reference group of the Dutch Reformed. The lower risks of the Jewish infants is in line with differences between Jewish and non-Jewish reported in previous studies on infant mortality in the 19th century both in the Netherlands (Van Poppel et al., 2002) and elsewhere (Connor, 2017; Derosas, 2003; Sawchuk et al., 2013). Within the Protestant population, the more orthodox denomination of the Restored Evangelical Lutherans stand out in a negative way (hazard ratio 41% higher). The Roman Catholics appear not to be worse off than the Dutch Reformed majority, contrary to results from other studies (Van Poppel et al., 2002; Van Poppel, 1992). Due to presumably different registration practices of stillbirths between Jews and Catholics, IMRs and stillbirth rates might be either too high or too low for these denominations (Derosas, 2004b; Snel & Van Straten, 2006). The stillbirth rate for Catholics (57 per 1,000 births), however, is only slightly higher than that of the Dutch Reformed (54) and even slightly lower than that of the other Protestants. The stillbirth rate is the highest for the Dutch Jewish (76), but lowest for the Portuguese Jewish (37). Although the relatively high stillbirth rates of the Dutch Jewish do indicate stillbirth registration practice differences in comparison with other religious denominations, these stillbirth rate differences do not change the general pattern of infant mortality differences between the religious denominations (Figure 6).

6.2 | Social class

Infant mortality risk differences appear to be much smaller between social classes than between religious denominations. However, social class and religious denomination are related. The elite and middle class are overrepresented particularly among the Walloon Reformed and the Remonstrants, the more liberal Protestants. The Dutch Jews and Portuguese Jews show a mixed pattern: Among them, both the unskilled labourers and middle class are overrepresented. However, this should be interpreted with care because the rather common occupation of merchant ("koopman") in this group[11] is classified according to the Social Power scheme as a middle class occupation, whereas in practice a lot of poor street-traders called themselves merchants as

[11]The occupation of "koopman" accounts for 30% of all occupations in the group of working proprietors in the wholesale and retail trade and 12% of all middle class occupations.

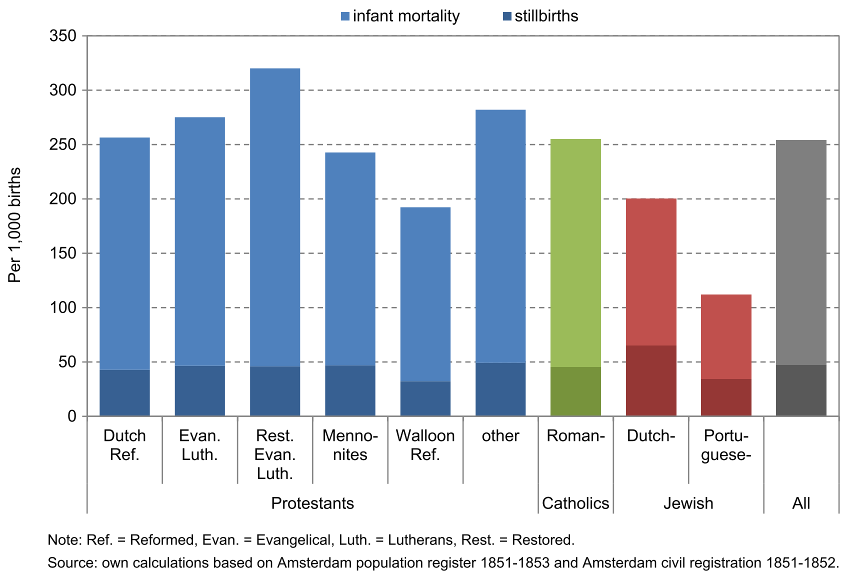

FIGURE 6 Infant mortality and stillbirth rates by religious denomination, Amsterdam, children born in 1851

well. Compared with Dutch Jews, among Portuguese Jews, the elite is also overrepresented. Controlling for religion (and all other variables) in the full model, the gradient of social class tends to decrease. The hazard ratios for social classes are roughly in line with the univariate analysis and many other studies including socio-economic status (such as Derosas, 2003; Jaadla & Puur, 2016; Van Poppel et al., 2002). However, none of the effects remain significant[12] and the relatively high effect of those with no (or unknown occupation) disappears.

6.3 | Other characteristics

Gradients of other sociodemographic characteristics in infant mortality are in line with results found by many other studies (Derosas, 2003, 2004a; Jaadla & Puur, 2016; Tymicki, 2009; Van Poppel et al., 2005). Boys face a higher infant mortality risk than girls (hazard ratio 1.20). Children born to older (hazard ratio 1.33) and younger (1.14) aged mothers are more vulnerable. Infant mortality risks are as expected particularly high among births to single mothers (hazard ratio 2.92), often with no occupation (44%), and among multiple births (hazard ratio 3.26). Both births to single mothers and multiple births, however, account for a rather small proportion of all births: respectively 5.0% to single mothers and 2.7% multiple births (108 twins and seven triplets).

Infant mortality is higher for those born in winter. However, the effect is not significant in the full model. Although the summer is considered the most risky time of the year to be born for infants according to a study by Van Poppel et al. (2002), other studies found high summer risks at the age of around 6 months for those born in the winter (Breschi & Livi-Bacci, 1986; Lee & Marschalck, 2002; Van Poppel, Ekamper, & Mandemakers, 2018). The association with the number of persons at the same address, population density, and tax value of the property is less clear, although, in line with other studies (Jaadla & Puur, 2016; Thornton & Olson, 2011; Xu et al., 2014), living in less densely populated housing decreases the hazard ratio by 19%. Living in a backstreet alley meanwhile increases the hazard ratio by 29%. On the other hand, contrary to the belief at that time that locations where “fresh air could freely run through,” like broader streets, were more healthy, it is the narrower streets that show a significant 27% lower hazard ratio. Although Jaadla and Puur (2016) found water supply to be the single most influential risk factor in Tartu, the patterns of water supply characteristics in our model are less clear. Living directly in front of a canal or the distance to the nearest surface water is not significant. Infant mortality is 39% higher where the fresh canal water quality is worst (especially in the east of the city) unlike in the lower lying areas (mainly in the west) with the worst quality groundwater. With regard to health care, particularly the role of midwives is found to be important (Edvinsson, Garðarsdóttir, & Thorvaldsen, 2008; Lazuka, Quaranta, & Bengtsson, 2016; Reid, 2002, 2017). In our analysis, indeed the distance to the nearest midwife matters, however, only living the furthest away from the nearest midwife increases infant mortality risk significantly, at 20%.[13]

6.4 | Multi episodes and stillbirths

Because other studies (Jaadla & Puur, 2016; Van Poppel & Van der Heijden, 1997) have shown that environmental and water supply factors gain importance after the first months of life, we also used a similar multiepisode Cox proportional hazards model for “early” infancy (Months 0–5) and “later” infancy (Months 6–11). The results of these two models are shown in data columns 3 and 4 of Table 2. Compared with the outcomes in the overall model in data column 2 of Table 2, we see that the higher infant mortality risk of boys is higher for later infancy. For later infancy, the effect of older mothers even increases, whereas the effect of younger mothers declines and becomes nonsignificant. The infant mortality risk of multiple birth infants remains high but declines for infants that survived the first 6 months. With respect to religious denominations, risks decline in later infancy for the Dutch

[12]Including religion–social class interaction effects (not shown) did not change main effect estimations.

[13]Distances to other medical practitioners (man-midwifes and medical doctors) appeared to be nonsignificant and were left out of the final model.

Jewish and increase in later infancy for the more orthodox Protestants (Restored Evangelical Lutherans, Mennonites, and the residual group of other Protestants). This might be related to different patterns for breastfed and artificially fed infants (Knodel & Kintner, 1977)—not only for the Jewish infants who were more likely breastfed much longer but also for the orthodox Protestants who might have been artificially fed at much earlier age.

A rather remarkable outcome is the significantly lower risks for people living in more populated housing. Some of the environmental and water supply factors, in line with Van Poppel and Van der Heijden (1997) and Jaadla and Puur (2016), seem indeed to be slightly more important for later infancy than early infancy: Infant mortality risks for older infants are lower for the least populated housing, higher for backstreet alleys (though not significant), and higher for housing near the bad water quality areas in the east. However, tax value and street width show effects opposite to expectations. Health-care effects of proximity to midwives show an expected but nonsignificant pattern.

Additionally, we compare stillbirth and infant mortality risks using logistic regression models including the same set of variables used in the previous Cox regression models. The outcomes (odds ratios) of the logistic regression model for the risk of infant mortality are as expected in line with the full Cox regression model. The odds ratios for the various religious denominations are all nonsignificant except for the Dutch Jewish (see Table 3). Contrary to the lower infant mortality risk, their stillbirth risk is substantially higher. This, however, seems to support the idea that Jewish stillbirth rates might be biased by overestimation because Jews were much more likely to register spontaneously aborted foetuses as stillbirths as soon as they could be recognised as a human being (Derosas, 2004b; Snel & Van Straten, 2006).

TABLE 3 Logistic regression model odds ratios (OR) for infant mortality and stillbirths by sociodemographic explanatory and control variables, Amsterdam, children born 1851

Variables	Infant mortality (Age 0–11 Months) OR	Stillbirths OR
Socio demographics		
Sex		
Male	1.24***	1.30***
Female	1.00	1.00
Age of mother at birth (in years)		
<25	1.13***	0.74
25–29	0.95	0.71**
30–34	1.00	1.00
35–39	1.05	0.99
40+	1.39***	1.20
Unknown	1.14	0.95
Single mother		
No	1.00	1.00
Yes	3.60***	3.53**
Multiple birth		
No	1.00	1.00
Yes	3.66***	1.90***
Religion		
Dutch Reformed	1.00	1.00
Evangelical Lutheran	1.11	1.14
Restored Evangelical Lutheran	1.48**	1.28
Mennonites	1.03	1.15
Walloon Reformed	0.83	0.73
Remonstrants	1.09	1.72
Other Protestants	1.57	0.93
Roman Catholics	1.00	1.07
Dutch-Jewish	0.67***	1.71***
Portuguese-Jewish	0.37***	0.79
Model		
Number of observations	8,124	8,636
Number of deaths	1.682	512
Log-likelihood	−3957.6	−1862.7
Likelihood ratio χ^2	370.9	154.2
Degrees of freedom	67	65
p value	0.00	0.00

Note. Full models include all other controls as presented in Table 2.
**p* < 0.1 significance. ***p* < 0.05 significance. ****p* < 0.01 significance.
Source: Amsterdam population register 1851–1853; Amsterdam civil registration 1851–1852.

6.5 | Neighbourhood diversity

The map presented earlier in Figure 1 displays the spatial pattern of the population by religion and population density, showing the densely populated areas at the border of the city, the spatially concentrated Jewish population east of the city centre, and the less densely populated canal district east and southeast of the city centre. The concentration of the Jewish population is confirmed by exploring the isolation index. We calculated isolation indexes for all egocentric neighbourhoods of individuals belonging to minority religious denominations and aggregated them into aggregated religious denomination group averages. With a predefined neighbourhood size of the nearest 400 neighbours,[14] the isolation index (at a scale from 0 to 1) for the Dutch Jewish is 0.70, followed by Roman Catholics (0.28), Portuguese Jewish (0.22), and all other denominations below 0.15 (see Table A1).[15] Similarly, we calculated the isolation indexes for all egocentric neighbourhoods of individuals belonging to the same social class. The aggregated isolation index is 0.10 for the highest class subgroup (elite) and 0.04 for the lowest social class (unskilled labourers). Consistently, the aggregated diversity index (at a scale from 0 to 1) for the whole city is lower for religious denominations (0.65) than for social classes (0.74). The isolation indexes clearly confirm the strong spatial concentration of the Jewish population. Spatial concentration of social classes appears to be much less clear. Social class isolation indexes calculated for smaller neighbourhood sizes increase slightly but remain low.

[14]Isolation indexes were calculated for different numbers of nearest neighbours starting from 25, 50, 100, 200, 400, and so on. We only present results for an egocentric neighbourhood size of the 400 nearest neighbours (see also Appendix A), providing a representative indication of the degree of isolation.

[15]The isolation index for the Dutch and Portuguese Jewish combined is 0.77.

Figure 4 presents the spatial distribution of the live births, stillbirths, and infant deaths. The map shows a similar pattern to the population density in the map in Figure 1: high numbers of births in the poor outskirts of the city and the Jewish neighbourhood, and low numbers in the canal district. The map does not show conspicuous concentrations of high numbers of infant deaths or stillbirths. Moran's I, a measure of spatial autocorrelation, was found to be close to zero for both infant mortality and stillbirths (0.006 for IMRs and 0.011 for stillbirth rates), indicating no spatial autocorrelation.

The results of the models estimated in the previous sections show that religion seems to have a much stronger relation with infant mortality than social class. We saw from the isolation indexes that spatial differences between the population compositions of Amsterdam neighbourhoods are also much more determined by religion than by social class. But to what extent are these religious differences between neighbourhoods associated with differences in infant mortality levels at the individual level? Did living in a neighbourhood dominated by the Jewish population, with relatively low IMRs, had beneficial effects on IMRs of non-Jewish living there? In line with

TABLE 4 Cox proportional hazards model hazard ratios (HR) for infant mortality by different model specifications of religion and religious diversity or dominance in the neighbourhood, Amsterdam, children born in 1851

	Model				
Variables	**I**	**II**	**III**	**IV**	**V**
Religious denomination of infant					
Dutch Reformed	1.00		1.00	1.00	
Other Protestant	1.12*		1.12*	1.11	
Roman Catholic	1.01		1.01	1.05	
Jewish	0.65***		0.68**	0.68*	
Neighbourhood diversity/dominance					
Diverse neighbourhood		1.00	1.00	1.00	
Jewish dominance		0.70***	0.95	0.99	
Catholic dominance		0.97	0.97	0.47	
Protestant dominance		0.94	0.95	1.13	
Religion of infant x neighbourhood diversity/dominance					
Dutch Reformed x diverse neighbourhood					1.13
Other Protestant x diverse neighbourhood				0.72	0.90
Roman Catholic x diverse neighbourhood				0.43**	0.51*
Jewish x diverse neighbourhood				0.99	0.76
Dutch Reformed x Jewish dominance					0.99
Other Protestant x Jewish dominance				1.28	1.40
Roman Catholic x Jewish dominance				0.59	0.61
Jewish x Jewish dominance				0.97	0.65***
Dutch Reformed x Catholic dominance					0.47
Other Protestant x Catholic dominance				3.79**	1.97*
Roman Catholic x Catholic dominance				2.13	1.04
Jewish x Catholic dominance				-	-
Dutch Reformed x Protestant dominance					1.00
Other Protestant x Protestant dominance					1.11
Roman Catholic x Protestant dominance					1.05
Jewish x Protestant dominance					0.68*
Model					
Number of observations	8,124				
Number of deaths	1,682				
Log-likelihood	−14,767.7	−14,773.0	−14,767.5	−14,760.6	−14,760.6
Likelihood ratio χ^2	375.8	365.1	376.1	390.0	390.0
Degrees of freedom	60	60	63	72	72
p value	0.00	0.00	0.00	0.00	0.00

Note. Full models include all other controls (except religious denomination) as presented in Table 2; Neighbourhood: egocentric neighbourhoods of nearest 400 neighbours. Neighbourhood diversity: diverse: diversity index <0.4; Jewish dominance: isolation index for Jewish population > 0.5; Catholic dominance: isolation index for Catholic population > 0.5; Protestant dominance: all others.

*p < 0.1 significance. **p < 0.05 significance. ***p < 0.01 significance.

Source: Amsterdam population register 1851–1853; Amsterdam civil registration 1851–1852.

the study of Sawchuk et al. (2013), who found Catholics living in Jewish neighbourhoods experiencing lower mortality, our hypothesis is that infant mortality is lower for non-Jewish living in Jewish neighbourhoods.

Table 4 presents the results of adapted versions of the previously used Cox regression models including not only the religious denomination of the infant but also the religious diversity or dominance in the neighbourhood. Neighbourhoods are characterised as being either relatively diverse or strongly dominated by one of the major denominations. For each individual birth, the neighbourhood characteristics are measured based on the concept of egocentric neighbourhoods. Here, we use the nearest 400 neighbours. For easier comparison, we use a condensed classification of religious denomination in four major groups. Including neighbourhood diversity (Model II) instead of religious denomination (Model I) into the model shows that infant mortality is, as expected, lower in neighbourhoods with Jewish dominance. However, including both religion of the infant and religious neighbourhood diversity/dominance (Model III) makes the Jewish neighbourhood dominance effect disappear. To test whether specific religious groups might have been favoured or disadvantaged by being born in neighbourhoods with similar or different religious dominance, we included the interactions between the infant's religion and religious dominance in the infant's neighbourhood (Model IV including main effects and Model V interaction effects only). The model estimations confirm the favourable position of the Jewish infants, not only within but also outside Jewish neighbourhoods (although none of them were born in Catholic dominant neighbourhoods). Catholic infants seem to be better off in neighbourhoods dominated by other religions. Remarkably, the non-Dutch Reformed Protestants seem to be even worse off when they are born in Catholic or Jewish neighbourhoods. Our results confirm the results of Sawchuk et al. (2013) with respect to the Catholics experiencing lower IMRs when living in Jewish neighbourhoods. However, this does not apply to other non-Jewish denominations.

7 | CONCLUSIONS AND DISCUSSION

Linking Amsterdam mid-19th century population register data and geographical cadastral data offers a unique dataset to study the relationship between infant mortality and socio-economic, residential, environmental, and health-care characteristics at the micro level of the households and dwellings. Using modern GIS, we were able to add a unique combination of several characteristics of the residential environment and health-care access to the commonly used demographic and socio-economic characteristics, such as the residential location relative to water supply and distance to the nearest midwife.

The results of the analyses confirm the favourable position of the Jewish population with respect to infant mortality—as shown in other studies as well. However, the population register data uniquely allow us to distinguish more precise religious denominations beyond the usual main Protestant, Catholic, and Jewish classification. Our results show large differences between denominations within the main groups. The Portuguese Jewish IMR is even more favourable than the Dutch Jewish. Although Jewish stillbirth rates are relatively high probably due to different religious practices in stillbirth reporting, as found in other studies as well (Derosas, 2004b; Snel & Van Straten, 2006), this does not affect the overall picture. Even if a portion of the Jewish stillbirths were classified as neonatal deaths, Jewish infant mortality maintains lower rates than other religious denominations. On the other hand, IMRs are less favourable for the more orthodox Protestant denominations like the Restored Evangelical Lutherans and more favourable for the more liberal Protestant denominations. This suggests, in line with Knodel and Kintner (1977), bottle feeding as opposed to breastfeeding at earlier ages among the more orthodox Protestant groups. Contrary to findings in other research, Catholics were not worse off than the major Protestant denominations in Amsterdam. However, most Dutch municipalities with a predominantly Catholic population and higher infant mortality risks were situated in the economically disadvantaged southern part of the Netherlands, and the spatial heterogeneity in the infant mortality patterns suggests that risk factors were not the same for every municipality: Differences in cultural, social, economic, and ecological circumstances may have shaped infant mortality risks in each municipality differently (Van den Boomen & Ekamper, 2015). Janssens and Pelzer (2014) studied four different Dutch towns throughout the country and indeed found important religious cultural differences between Catholics from different towns. They concluded that it was regions that were determining infant survival, not religion. As stated by Rogier (1962) in his extensive study on the history of Catholic Netherlands, mid-19th century Catholics in Amsterdam (and other cities in the west) were different—namely, less conservative and more developed—than Catholics from the more rural southern provinces. Moreover, the socio-economic composition of the Catholic population in Amsterdam in 1851 was more or less identical to the Protestant population.

IMRs for the higher social classes are more favourable, particularly for the elite and to a lesser extent the middle class. However, IMR differences are much smaller between social classes than between religions. IMRs are very high for (mostly unemployed) single mothers; however, except for this case, these socio-economic effects are not significant and, when accounting for religious denomination (and other characteristics), tend to diminish. This might be partly due to the small proportion of the elite (2.3% of all births) and the mixed interpretation of the occupation of merchant, which is classified as a middle class occupation but was often used by poor street-traders as well. Although many studies have found a beneficial effect of higher socio-economic class (such as Connor, 2017; Derosas, 2004a; Xu et al., 2014), others found insignificant effects (Jaadla & Puur, 2016; Thornton & Olson, 2011) or, and particularly for the pre-industrial mid-19th century period, a lack of socio-economic gradient (Edvinsson, 2004; Van Poppel et al., 2005).

Effects of other sociodemographic characteristics are in line with other research (such as Derosas, 2003; Jaadla & Puur, 2016; Tymicki, 2009; Thornton & Olson, 2011): Boys were much more vulnerable than girls; multiple birth children were particularly worse off; both the oldest and youngest mothers faced higher risks of infant mortality; and children born outside marriage had high risks of infancy death and stillbirth.

Whether housing and neighbourhood conditions reinforced or weakened infant mortality is not entirely clear, a picture also emerging from other studies (Connor, 2017; Jaadla & Puur, 2016; Thornton & Olson, 2011; Xu et al., 2014). As one would expect, living in less densely populated housing weakened infant mortality risks, whereas living in the poorer backstreet alleys reinforced them. On the other hand, living in more expensive—presumably better quality—housing or in less populated buildings ultimately did not weaken mortality risks. This could be due to missing measurements of household size. Because household size could not be measured, only the number of persons living at the same address could be used. Particularly in the poorer areas, often several households lived at the same address simultaneously.

In housing directly along the canals, IMRs were more favourable but not significantly so. This might be due to opposite effects: Living along the canals meant living near to polluted and contaminated water on one hand and, on the other hand, meant better access to fresh water supplied from elsewhere and sold from boats via the canals. Although infant mortality might have been sensitive to the disease environment, our results do not show clear spatial patterns. Bad quality canal water particularly weakened IMRs in the east of the city, but not in the densely populated west, where both the canal water quality and groundwater quality was worse, due to it being at or below sea level. Because the city was lacking a proper sewer system until the beginning of the 20th century, the typical Dutch dense urban canal infrastructure probably easily and strongly contributed to an unfavourable disease environment throughout the city. Although water quality was only measured in a very rough way, differences in canal water quality should probably be seen as ranking from very bad to less bad rather than from bad to good.

Living near the public cisterns did not seem to affect infant mortality. However, the public cisterns were primarily meant for the brewers and not the main fresh water source for the population. Unfortunately, the Amsterdam data lack information on household access to water supply and sanitation, as used in for instance the study from Jaadla and Puur (2016) on the Estonian city of Tartu. In line with Van Poppel and Van der Heijden (1997) and Jaadla and Puur (2016), we do find that the effects of environmental conditions are more pronounced in later stages of infancy and less important in the early stages of infancy and for stillbirths.

In the mid-19th century, health care around childbirth was limited; childbirth was still mainly a matter for midwives. The role of obstetricians increased in importance as education around childbirth improved through the second half of the 19th century; they began being more involved on a regular basis—not just for complicated births (Van Lieburg & Marland, 1989). Although information on individual use of health care is unavailable, the data suggest that living further away from the most obvious health care, the nearest midwife, increased infant mortality risks, which supports findings from studies on aggregate-level data (Edvinsson et al., 2008; Lazuka et al., 2016) and micro-level data (Reid, 2002, 2017).

All in all, residential and neighbourhood conditions do seem to be associated with infant mortality risks. But contrary to the worries of medical doctors at the time over the enormous mortality risk differences between the higher and the lower classes, infant mortality differences between social classes seem to be less prominent. Like Smith (1991) argued that it was location that mattered most for mortality variation, not the social class of individuals, and Garrett, Reid, and Szreter (2010) showed for the United Kingdom that social class differentials in infant mortality are largely due to the local micro-environment. At the urban level, it was assumed that it was the separation of different social classes in distinct residential areas that mattered (De Swaan, 1988). Where people lived seemed to be more important than to what social class people belonged.

Particularly, the Jewish population, however, even living as densely as they did in the city, was apparently able to avoid the negative effects of that density. Their relatively low infant mortality might very well be explained by the isolation of the Jewish community and their infants from other religious groups (Van Poppel et al., 2002), their group solidarity, religious precepts, and secular knowledge of health (Sawchuk et al., 2013). Thornton and Olson (2011) found similar beneficial infant and childhood mortality effects for strongly segregated Protestant and Catholic communities in Montreal. Connor (2017), however, concluded that child mortality differences in Dublin had their roots in poverty and residential inequality rather than in Irish or Catholic behaviours. Taking neighbourhood religious diversity and dominance in Amsterdam into account shows that it was not necessarily primarily the isolation of the Jewish community that mattered, because the Jewish advantage was not restricted to the Jewish-dominant areas. Because not all other religious denominations living in Jewish-dominant areas had favourable infant mortality risks, neither does it seem likely that it was the residential area that primarily mattered here. Because especially the more orthodox Protestants faced high infant mortality risks in the Jewish neighbourhoods, it was most likely the Jewish lifestyle, the breastfeeding and religious practices that made the difference. In general, religion seemed to be more important than social class, a notion that has already been emphasised in Dutch studies from the beginning of the 19th century. Using alternative social class classifications might produce different results. However, parts of the Jewish population (especially merchants) were probably assigned a too high social class status in our study, implying that the Jewish infant mortality risks were in fact even more favourable compared with other religious denominations. Of course this study is lacking a longitudinal perspective by only presenting a mid-19th century snapshot. During the course of the 19th and 20th century, the role of socio-economic status may have become more important.

Although residential and neighbourhood conditions in mid-19th century Amsterdam do seem to be associated with infant mortality risks, their effects seem to be less important than individual socio-economic characteristics (especially religion) unlike findings from some other studies. Jaadla and Puur (2016), for instance, found the source of water supply the single most important factor in Tartu, and Connor (2017) found residential inequality more important than Irish or Catholic behaviours in Dublin. Thornton and Olson (2011) found neighbourhood effects as large as household effects for three strongly segregated religious communities in Montreal. In Amsterdam, it was only the Jewish community that lived strongly segregated from the rest. However, taking both Jewish neighbourhood domination and individual religious denomination into account made the neighbourhood domination effect disappear.

The Amsterdam mid-19th century population register data—combining census listings with vital registration—are an important source for the study of infant mortality. However, population register data have problems as well (see, for instance, Alter, 1988). Particularly for studying infant mortality, the population register data had to be supplemented and corrected for missing or unidentified births and duplicate registries from the civil registration. Compared with the birth register of the civil registration, 8.4% of all registered live births were missing from the population register. Stillbirths, 5.9% of all births, were not registered at all in the population register and had to be added from the death register of the civil registration.

As in many other studies on 19th century infant mortality, the availability of additional data is limited, which forces scholars to use rough indicators. As mentioned, data on individual household access to water supply and sanitation are unfortunately lacking, as well as data on, for instance, individual (breast) feeding practices and actual health-care use. Our population register dataset also lacks reliable data on the actual family size, birth rank, and whether for instance the mother died within the first year of the infant's life. Another drawback of the current dataset is a missing longitudinal component. One new research direction using the data would be to extend the dataset by following-up the same birth cohort over their lifetime; another would be to expand the dataset with additional birth cohorts. Extending the dataset by following up on the cohort would also allow scholars to study long-term health and mortality effects of early life circumstances. However, this not only requires the addition of demographic life course events but also, if one wants to take the spatiotemporal context into account as well, implies dealing with the complex matter of geocoding the longitudinal demographic data (Hedefalk, Pantazatou, et al., 2017). Adding new birth cohorts would allow the study of urban infant mortality changes over time, requiring digitising population register data for later years from for instance Amsterdam Population Register scans, available for the periods 1854–1863 and 1874–1893. Additionally, linking the population register data to cause of death data, such as the Amsterdam, 1854–1940 (currently in development[16]), might provide better insight into morbidity.

CONFLICT OF INTEREST

We have no conflict of interest to declare

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APPENDIX A

TABLE A1 Spatial Isolation indexes and aggregate diversity index for minority religious denominations, Amsterdam, The Netherlands, 1851

Religious denomination	Isolation index
Dutch-Jewish	0.704
Roman Catholics	0.281
Portuguese-Jewish	0.222
Evangelical Lutheran	0.142
Restored Evangelical Lutheran	0.059
Walloon Reformed	0.043
Mennonites	0.034
Remonstrants	0.018
Other protestants	0.018
Aggregate diversity index	0.654

Note. For spatial isolation index calculation method, see Östh et al. (2015).

Source: Own calculations based on Amsterdam population register 1851–1853, Amsterdam civil registration 1851–1852, and HISGIS Amsterdam.